Steering Controller Design of Automated Driving Bus

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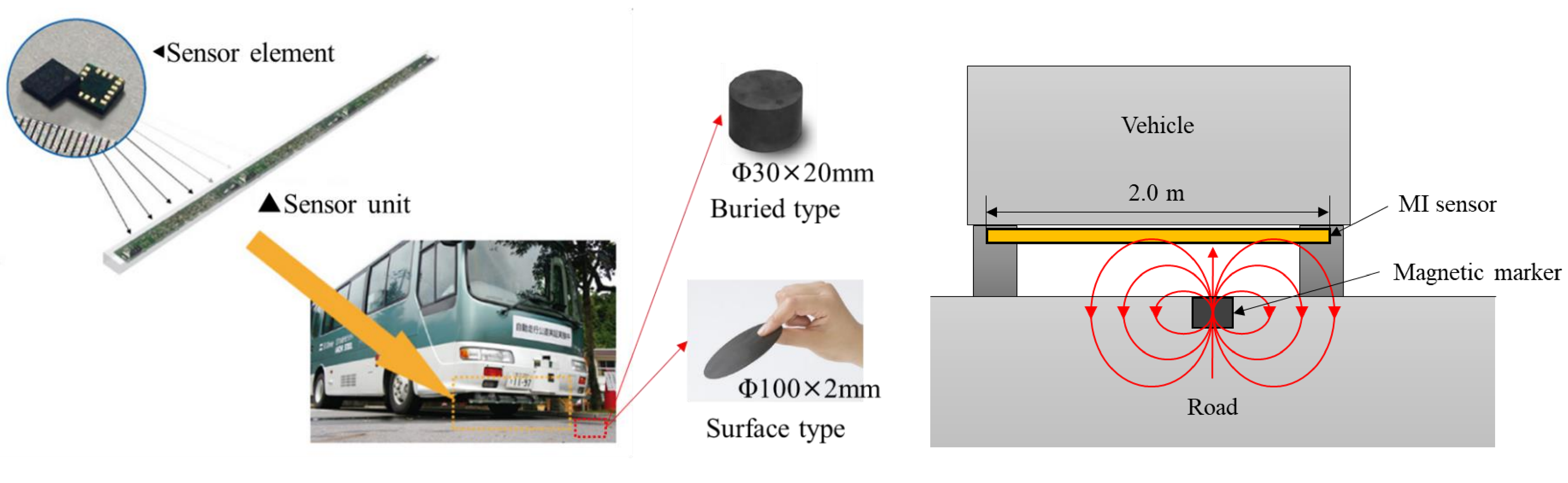
Introduction

There are high expectations for the development of automated buses and driverless bus operation in developed countries because of the aging population and the gradual shortage of transportation. Since only onboard sensors are not enough for measuring precise position of the vehicle, infrastructures such as magnetic markers are expected to correct it. However, comparison between infrastructures and sensors, and the appropriate interval of markers have not been stated explicitly.

Localization



Global Magnetic Positioning System (GMPS)

$$x = \begin{bmatrix} l \\ y \\ \theta \\ k_v \\ \gamma_b \\ k_\beta \end{bmatrix}$$

- l …Longitudinal position
- y …Lateral position
- θ …Yaw angle
- k_v …**Scale factor of speed**
- γ_b …**Bias of yaw rate**
- k_β …**Scale factor of sideslip angle**

Parameter estimation

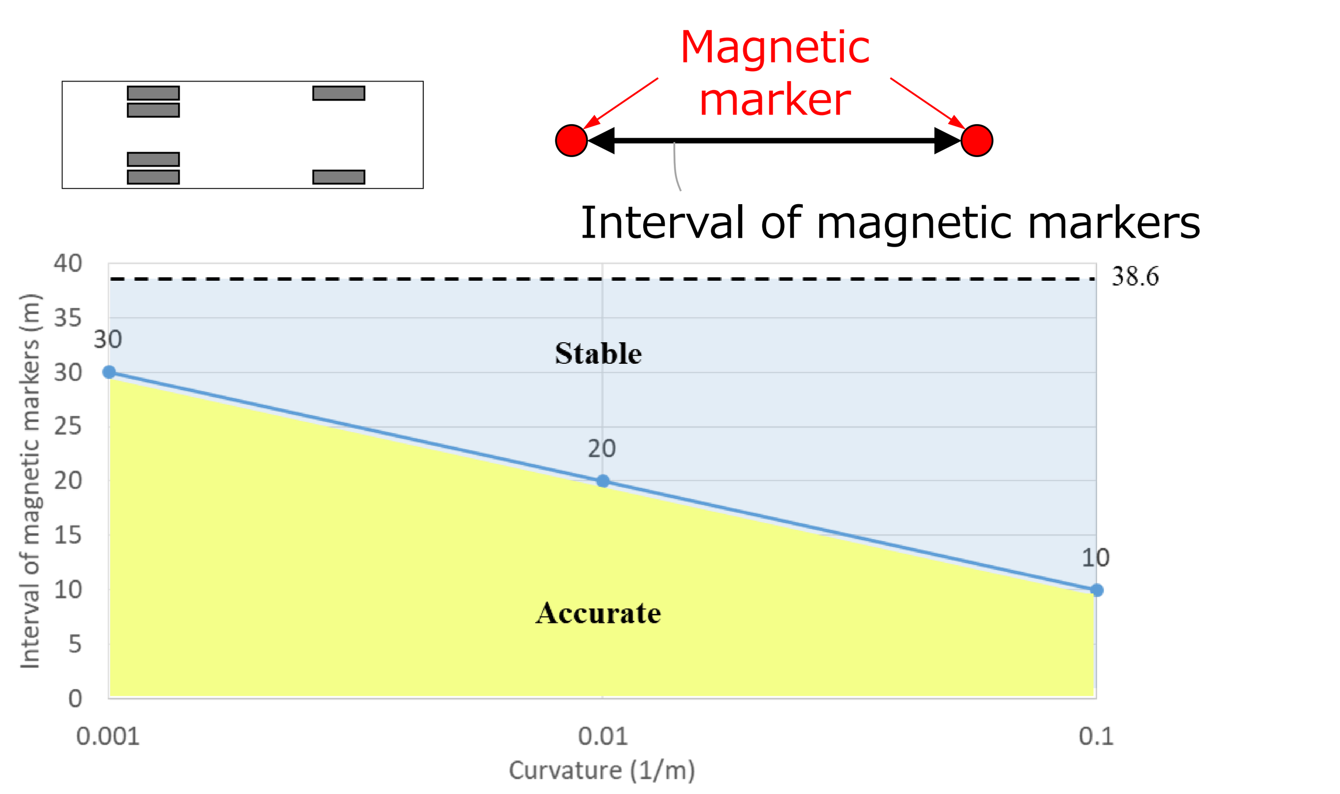
Kalman gain

$$G_k = P^-{}_k C_k{}^T \left(C_k P^-{}_k C_k{}^T + Q\right)^{-1}$$

Update estimate

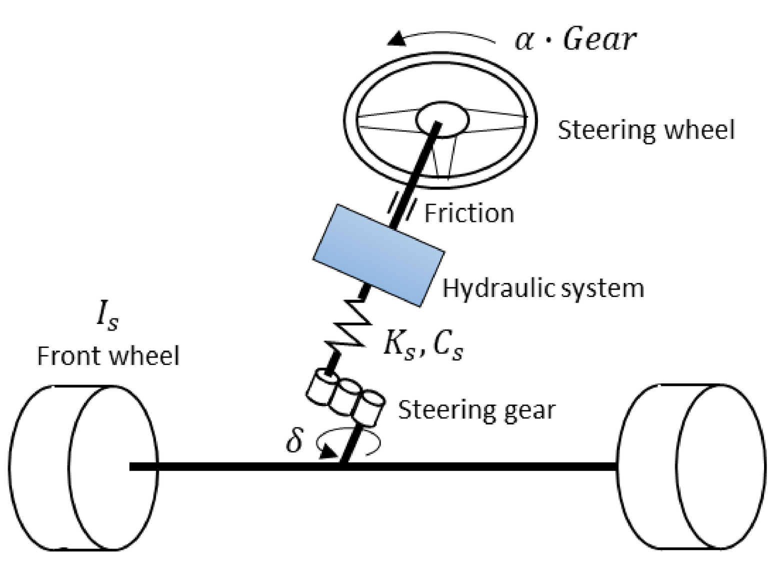
$$\hat{\boldsymbol{x}}_k = \hat{\boldsymbol{x}}^-{}_k + G_k\left(\boldsymbol{y}_k - C_k \hat{\boldsymbol{x}}^-{}_k\right)$$

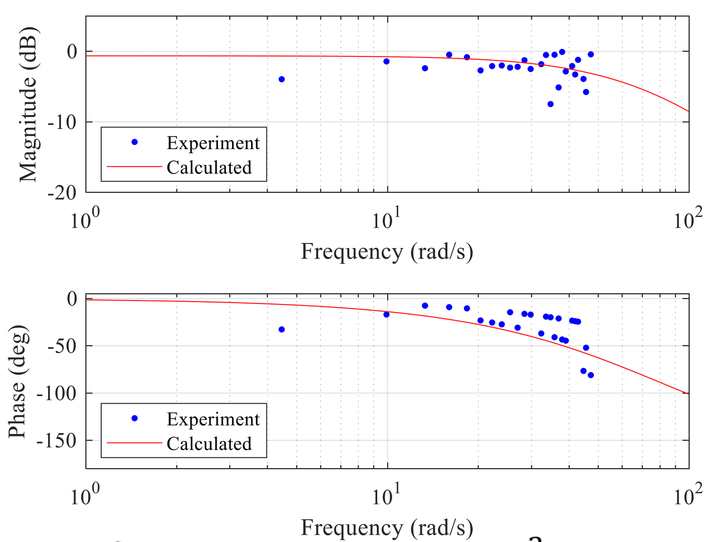
Extended Kalman filter with GMPS has large potential for increasing interval of magnetic markers, which is currently set as 2m for safety operation.



Appropriate interval of magnetic markers

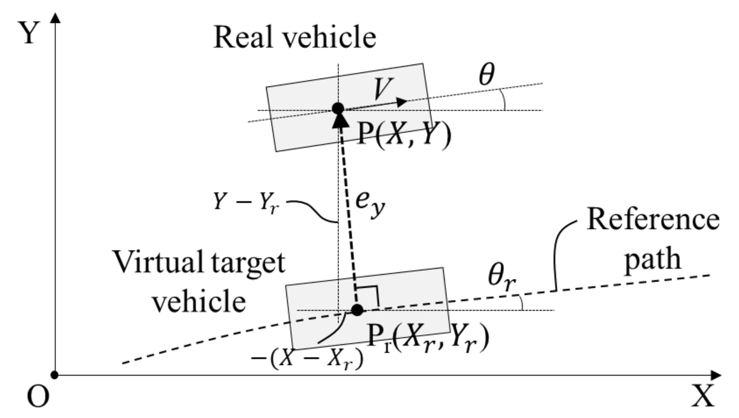
Steering control





$$\frac{\delta}{\alpha} = G_s(s) = K\frac{\omega_s{}^2}{s^2 + 2\zeta_s\omega_s s + \omega_s{}^2}$$

Modelling of steering system

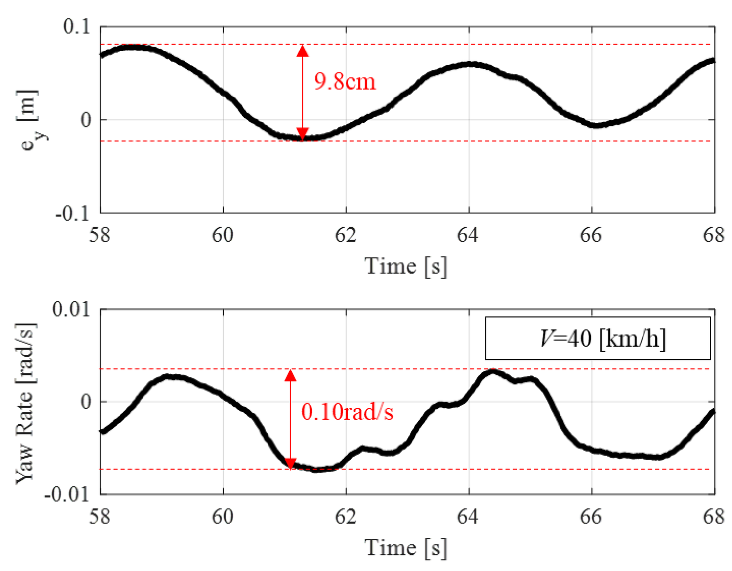


Definition of error

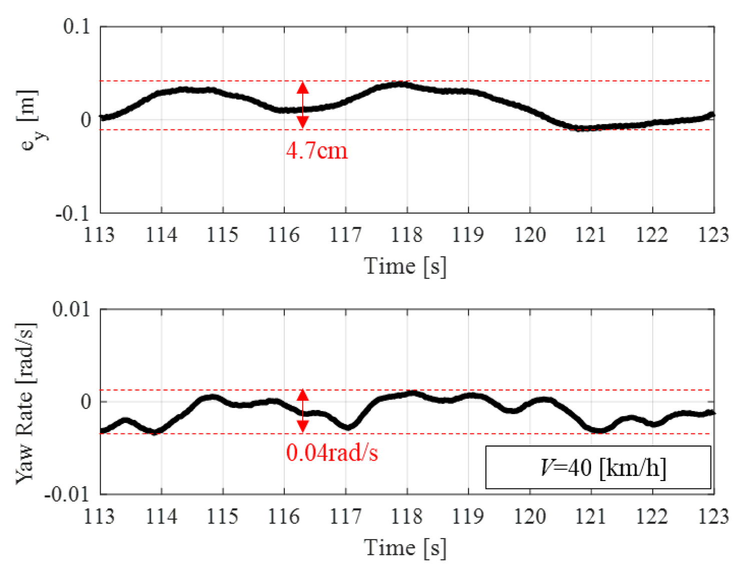
$$\frac{d}{dt}\begin{bmatrix} y \\ \dot{y} \\ \theta \\ \dot{\theta} \\ \delta \\ \dot{\delta} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & -a_1 & -a_2 & -a_3 & b_1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & -a_4 & -a_5 & -a_6 & b_2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & -\omega_s{}^2 & -2\zeta_s\omega_s \end{bmatrix}\begin{bmatrix} y \\ \dot{y} \\ \theta \\ \dot{\theta} \\ \delta \\ \dot{\delta} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ \omega_s{}^2 \end{bmatrix}\alpha + \begin{bmatrix} 0 \\ d_1 \\ 0 \\ d_2 \\ 0 \\ 0 \end{bmatrix}$$

$$\alpha = -\left[\mathrm{K_y} \quad \mathrm{K_{\dot{y}}} \quad \mathrm{K_\theta} \quad \mathrm{K_{\dot{\theta}}} \quad \mathrm{K_\delta} \quad \mathrm{K_{\dot{\delta}}}\right]\left[y \quad \dot{y} \quad \theta \quad \dot{\theta} \quad \delta \quad \dot{\delta}\right]^T$$

The transfer lag from the steering wheel input to the front wheel angle is measured and modelled as the second-order system. A novel six-state feedback control with gain scheduling is proposed to obtain the optimal damping.



Two state variables (y,θ) FB

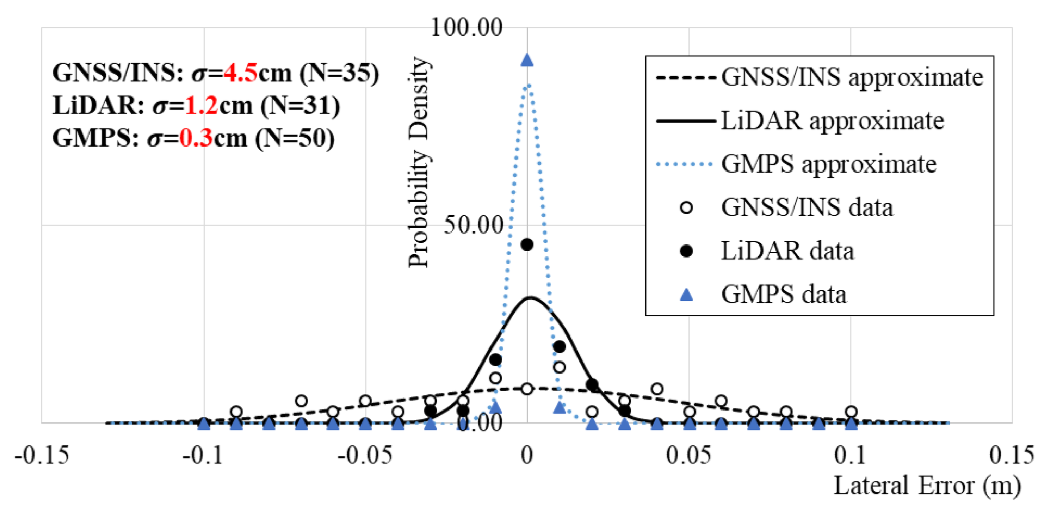


Six state variables FB

Pilot tests

(a) GNSS outage (b) Snow-covered

Experimental conditions



(a) Precision docking control (b) Accuracy of precision docking

Experimental results of precision docking

Automated driving bus has travelled over 10,000 km successfully within suburban/urban environments in Japan. The standard deviation of lateral error in precision docking using GMPS or LiDAR was under 1.25 cm, which is the criterion required for the precision docking. Experimental results also show GMPS is much robust since it provides high accuracy even in severe conditions.

Publications

Ando T., Kugimiya W., Hashimoto T., Momiyama F., Aoki K., and Nakano K., "Lateral Control in Precision Docking Using RTK-GNSS/INS and LiDAR for Localization," *IEEE Transactions on Intelligent Vehicles*, Vol.6, No.1, 2021, pp. 78-87.

Ando T., Mukumoto, H., Aoki K., Okazaki S., Nagao T., Aoyama H., Yamamoto M., Nakano K., "Localization Using Global Magnetic Positioning System for Automated Driving Bus and Intervals for Magnetic Markers", *IEEE Transactions on Intelligent Vehicles*, online:2022.3, DOI:10.1109/TIV,2022.3155324